

US-EPR Technology Manual

Chapter 7.0

**STEAM GENERATOR TUBE RUPTURE AND
SMALL-BREAK LOSS-OF-COOLANT ACCIDENT MITIGATION**

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7.0 STEAM GENERATOR TUBE RUPTURE AND SMALL-BREAK LOSS-OF-COOLANT ACCIDENT MITIGATION

Learning Objectives:

1. State the design requirements imposed on the US-EPR for mitigating steam generator tube ruptures (SGTRs) and small-break loss-of-coolant accidents (SBLOCAs).
2. Explain the US-EPR response to an SBLOCA.
3. Describe the US-EPR response to an SGTR.

7.1 Introduction

The US-EPR design employs a number of features to mitigate postulated SGTRs and SBLOCAs. Although the mitigation strategies are similar to those for current PWRs, the combination of features, including system automation, is unique to the US-EPR.

7.2 Design-Basis Requirements

The design-basis requirements imposed on the US-EPR for mitigating SGTR events can be summarized as follows:

- Radiation doses to personnel in the main control room and to the public at the exclusion area boundary are within applicable regulatory limits.
- Overfill of the affected steam generator is precluded to prevent introduction of liquid into the steam lines.
- No operator action is required to mitigate the event prior to 30 minutes.

The design-basis requirements imposed on the US-EPR for mitigating SBLOCA events can be summarized as follows:

- The acceptance criteria specified in 10 CFR 50.46 are met.
- Radiation doses to personnel in the main control room and to the public at the exclusion area boundary are within applicable regulatory limits.
- No operator action is required to mitigate the event prior to 30 minutes.

7.3 Mitigation Strategies

7.3.1 SGTR Mitigation Considerations

The mitigation strategy for an SGTR is similar to that for existing PWRs:

- Add liquid to the reactor coolant system (RCS) to make up for the leakage through the ruptured tube.

- Cool and depressurize the RCS to reduce the leak rate.
- Isolate the affected steam generator (SG) to terminate any release of radioactivity and to maintain doses to the public and main control room personnel within limits.
- Prevent liquid discharge through main steam safety valves (MSSVs) on the affected SG to ensure that the affected SG remains isolated from the environment.

To preclude the possibility of liquid discharge through the MSSVs on the affected SG, which could lead to a significant release of fission products to the atmosphere, the shutoff head of the medium head safety injection (MHSI) pumps is set to a value less than the lift setpoint of the MSSVs. This means that operator action is not required to throttle MHSI flow to prevent SG overfill or MSSV lift.

Furthermore, isolation of the affected SG is automated as part of the protection system. After the RCS is cooled and depressurized (see the discussion of the partial cooldown function below), the affected SG, as identified by high-high secondary liquid level or high N-16 radiation, is automatically isolated by the protection system.

7.3.2 SBLOCA Mitigation Considerations

The mitigation strategy for loss-of-coolant accidents (LOCAs) for the US-EPR is similar to that for the existing fleet of PWRs. A combination of safety injection (medium head and low head) and passive accumulators are used to ensure core cooling during a postulated LOCA.

However, the selection of the MHSI shutoff head as it relates to the mitigation of an SGTR has an effect on the ability to mitigate certain SBLOCAs. For certain break sizes, the energy removal through the break is insufficient to automatically depressurize the RCS. In these cases, heat is transferred to the SGs. The primary system pressure equilibrates to a value near that of the SG secondary pressure. If the SG pressure setpoint is greater than the shutoff head of the MHSI pumps, no MHSI-discharged liquid enters the RCS (Figure 7-1).

Consequently, the US-EPR design employs automatic depressurization of the SGs to ensure adequate MHSI flow into the RCS. Specifically, upon a low-low pressurizer pressure signal (used to actuate safety injection), the SGs are depressurized to 870 psia at a controlled rate by the main steam relief trains (MSRTs). The depressurization rate is controlled by the automatic reduction of the secondary pressure setpoint from the post-trip setpoint (approximately 1385 psia) to 870 psia at a constant rate over approximately 20 minutes, which is equivalent to a ramped reduction in secondary saturation temperature of about 180°F/hr.

This automatic depressurization function is called partial cooldown. All components necessary to perform a partial cooldown are safety-related, including the instrumentation, power supplies, and MSRT valves. Reducing the steam pressure to 870 psia is sufficient to decrease primary system pressure so that adequate MHSI

flow is supplied for the full spectrum of SBLOCAs (Figure 7-2). Because partial cooldown is automatic, operator action prior to 30 minutes is not required.

7.4 Small-Break Loss-of-Coolant Accident Scenario

The postulated SBLOCA is defined as a break in the reactor coolant pressure boundary (RCPB) that has an area of 0.5 ft² or less (approximately 10% of the cold-leg pipe cross-sectional area). This range of break areas encompasses the small lines that penetrate the RCPB. Small breaks could involve relief and safety valves, charging and letdown lines, drain lines, or instrumentation lines. The most limiting break location is in a cold-leg pipe at the discharge side of the reactor coolant pump (RCP). This break location results in the largest amount of inventory loss and the largest fraction of emergency core cooling system (ECCS) fluid being ejected outward through the break. This break produces the greatest degree of core uncover and the longest fuel rod heatup time; consequently, it poses the greatest challenge to meeting the 10 CFR 50.46 acceptance criteria.

The SBLOCA cases are analyzed until the top of the active fuel is recovered with a two-phase mixture and the cladding temperatures are reduced to temperatures near the saturation temperature. The SBLOCA is a loss of reactor coolant inventory that cannot be offset by charging from the chemical and volume control system (CVCS). Because the CVCS is not a safety-related system, it is assumed to be unavailable for mitigating an SBLOCA.

The loss of primary coolant causes a decrease in primary system pressure and in pressurizer level. A reactor trip (RT) occurs on low pressurizer pressure or low hot-leg pressure. The RT automatically trips the turbine and closes the main feedwater (MFW) full-load isolation valves. For cases involving the loss of offsite power (LOOP), it is assumed that the LOOP occurs coincident with the RT. This also terminates MFW. The secondary-side pressure increases, and because of the unavailability of the steam dump to the main condenser, the MSRTs relieve steam to the atmosphere. The SGs are fed by the emergency feedwater system (EFWS), which is actuated by the combination of the safety injection signal (SIS) and the LOOP.

An SIS is actuated on low-low pressurizer pressure. The SIS automatically starts the MHSI and low head safety injection (LHSI) pumps and initiates a partial cooldown of the secondary system, which causes the primary system to cool down and decrease in pressure. During the partial cooldown, RCS pressure decreases and MHSI begins. The partial cooldown of the SGs is via MSRT steam relief to the atmosphere. This cooldown automatically decreases the main steam relief control valve (MSRCV) setpoints at a rate corresponding to 180°F/hr to a value low enough to permit MHSI injection, while still high enough to prevent core recriticality. For the smallest breaks, the volume of flow through the break is less than the volume addition by MHSI and steam production in the core due to the decay heat. For those cases, depressurization of the RCS therefore stops at the end of the partial cooldown.

The RCS inventory continues to decrease as long as MHSI is insufficient to compensate for the break flow rate. The break flow rate decreases as the void

fraction in the cold legs increases. When the break flow changes to single-phase steam, the ratio between steam production due to core decay heat and steam venting at the break shifts. The break size then might become the dominant factor for the subsequent depressurization sequence:

- For the smallest breaks, some condensation in the SG tubes may occur in conjunction with the direct steam venting at the break to remove all steam produced in the core. The RCS pressure remains slightly above the SG pressure.
- Larger breaks vent sufficient steam so that further RCS depressurization occurs without steam condensation in the SG tubes (eventually the heat transfer reverses between the primary and secondary sides). RCS pressure decreases independent of the SG temperature to the accumulator discharge pressure, and possibly to the LHSI injection pressure.

The subsequent evolution of the RCS water inventory depends on the balance between ECCS flow rates and break flow rate. The core may uncover before the rate of ECCS water addition exceeds the loss of RCS coolant out the break. If so, the fuel clad temperature rises above the saturation temperature in the uncovered part of the core.

Two break spectrums are analyzed: one assumes a loss of offsite power concurrent with reactor trip, the other assumes offsite power available with delayed RCP trip. The single-failure criterion is satisfied by assuming the failure of one train of the ECCS and the EFWS. In addition, one train of the ECCS and one train of the EFWS are assumed unavailable because of maintenance, leaving active only two MHSI pumps, two LHSI pumps, and two EFW pumps. All four accumulators are assumed to inject.

The EFWS is actuated on the combination of LOOP and SIS or on SG low wide-range level. The two active trains of MHSI are assumed to inject respectively into loop 4, the broken loop, and into loop 1, the intact loop adjacent to the broken loop. The adjacent loop is chosen because it provides the greatest opportunity for safety injection to flow directly to the break and bypass the core. Figure 7-3 shows the RCS loop arrangement.

The loop seal (Figure 7-4) elevations on the broken loop (loop 4) and the adjacent intact loop (loop 1) are biased so that they are one foot lower than the loop seals in the other two loops. This bias makes the seal in the broken loop less likely to clear before the ones in the intact loops. Sensitivity analyses show that for SBLOCAs, higher peak cladding temperatures (PCTs) result when the loop seal in the broken loop remains plugged longer than the ones in the intact loops.

The SBLOCA cases are analyzed over a spectrum of break sizes ranging from 2.0 in. to 8.0 in. in diameter in 0.5-in. increments. The breaks are located in the RCP discharge piping. The break spectrum cases fall into two categories: (a) with LOOP assumed, in which the RCPs trip on RT; and (b) without LOOP, in which the RCPs continue to operate after RT and are tripped on low ΔP across two of the four RCP pumps. (The US-EPR design incorporates an automatic safety-related RCP trip for

SBLOCA mitigation when there is an 80% ΔP across the pumps in combination with an SIS.) The 6.5-inch break with LOOP produces the limiting PCT. Table 7-1 presents the sequence of events for that case.

After the initiation of the break, the primary pressure drops rapidly to the saturation point (Figure 7-5). An RT occurs at 4.49 sec due to low hot-leg pressure. All RCPs trip because of the LOOP that occurs simultaneously with the RT. Depressurization of the RCS plateaus at about 25 sec as the primary system saturates.

Initially, the secondary-side pressure increases rapidly due to the closing of the turbine stop valves at the time of the RT. This pressure increase is halted by the opening of the main steam relief isolation valves (MSRIVs) at about 114 sec, which causes a drop in secondary pressure of about 40 psi (Figure 7-5). SG pressure decreases when the MSRIVs first open, with the MSRCVs at 40% open. Because the SG pressures drop below the target value of the partial cooldown, the MSRCVs stroke closed at 134 sec. At about 170 sec, the MSRCVs reopen when the SG pressures intersect the cooldown curve. From 170 sec to the end of the transient, the MSRCVs modulate to depressurize the secondary at a rate corresponding to 180°F/hr. At about 255 sec, the primary pressure drops below the secondary pressure.

RCS depressurization increases when the break uncovers at about 250 sec and the break flow transitions from two-phase flow to steam-only flow (Figure 7-6). The loop seals of loops 2 and 3 completely void at 234 and 237 sec, respectively (Figure 7-7). This condition creates a flow path for the steam to vent out of the break. The depressurization continues until the accumulator flow begins at about 346 sec, at which time the pressure increases slightly (Figure 7-8). Loops 1 and 4 then clear at 360 and 362 sec, respectively.

RCS inventory and, consequently, collapsed liquid level in the hot assembly fall rapidly as primary fluid is lost out of the break (Figure 7-9). At about 246 sec, two MHSI pumps begin to inject into loops 1 and 4. However, the inventory lost out the break exceeds that supplied by the MHSI pumps, resulting in a net RCS inventory loss and core uncover. The PCT of 1638°F occurs at 360.26 seconds.

The large quantity of water supplied by the accumulators terminates the net loss of primary coolant inventory, thereby recovering the core level and ultimately quenching the core. As the RCS depressurizes further, the MHSI and LHSI eventually exceed the break flow and provide adequate long-term RCS coolant inventory.

The analysis demonstrates that the 10 CFR 50.46 acceptance criteria are met as follows:

- A PCT of 1638°F is calculated for the limiting case. This is below the 2200°F PCT limit specified in 10 CFR 50.46(b)(1).
- The total cladding oxidation at the PCT location is 0.383% of the total cladding thickness for the limiting case. This is below the 17% limit specified in 10 CFR 50.46(b)(2).

- The hydrogen generated in the core during the SBLOCA by cladding oxidation, 0.00897% of the hypothetical amount that would be generated by oxidation of all the cladding surrounding the fuel, is below the one percent limit specified in 10 CFR 50.46(b)(3).
- The core retains a coolable geometry. Thus, the coolable-geometry criterion in 10 CFR 50.46 (b)(4) is satisfied.

7.5 Steam Generator Tube Rupture Scenario

The SG tube rupture event is defined as the double-ended rupture of a single SG tube. The main acceptance criterion for this event is to maintain the radiological releases below acceptable limits. A secondary criterion is to prevent overfill of the SG secondary to prevent water from entering the steam lines.

The tube rupture is postulated to occur in the shortest SG tube, near the tube sheet location, to maximize break flow. Primary coolant from the RCS begins to enter the secondary system, driven by the pressure differential between the RCS and the secondary side of the SG. The inventory, pressure, and activity in the affected SG increase.

The break flow begins to depressurize the RCS and to decrease the pressurizer level. The CVCS charging pumps inject water into the cold legs to maintain pressurizer level. On the secondary side, the MFW flow to the affected SG decreases in response to the SG level increase.

Radiation monitors located in the steam lines and blowdown lines detect increased activity soon after the break occurrence and indicate the affected SG. Although high activity in a steam line (or high SG level) in combination with the initiation of partial cooldown isolates the affected SG, this function is not credited in the SGTR analysis. Another indication to the operator is the mismatch between the feed and steam flows of the affected SG.

If one charging pump cannot keep up with the break flow and the pressurizer level continues to decrease, a second charging pump (normally in standby) is automatically started on low pressurizer level. The letdown flow is automatically reduced to its minimum value in response to the decreasing level. The charging pumps initially take suction from the volume control tank. The pumps are automatically switched to the in-containment refueling water storage tank (IRWST) on low level in the volume control tank. The combined output of the charging pumps offsets the coolant loss through a single tube rupture. The operator trips the reactor before the RCS pressure decreases sufficiently to trigger an automatic RT.

If the charging pumps are not available, an automatic RT on low pressurizer pressure, high SG pressure, or high pressurizer pressure occurs, depending on the effect of break flow on the ruptured SG's pressure and on reactivity feedback. The pressurizer heaters are de-energized as the pressurizer level continues to decrease.

The break is assumed to occur near the tube sheet because that location maximizes the break flow (lower hydraulic resistance), and on the hot-leg side of the tube because that location maximizes the fraction of the break flow that flashes. The analysis is initiated from full power conditions. The analysis assumes the maximum number of plugged SG tubes, five percent, to minimize heat removal. This assumption leads to a lower initial SG pressure, which increases break flow and flashing fraction.

The analysis assumes that the primary coolant average temperature is at the lowest allowed temperature for full power (584°F, corresponding to coastdown at end-of-cycle conditions) because the low temperature leads to a lower initial secondary pressure and slightly higher integrated flashed mass.

Regardless of the initiating scenario, mitigation of the event is accomplished through automatic or manual isolation of the affected SG to terminate radiological releases, and through the reduction of RCS pressure to minimize the differential pressure across the ruptured tube. Minimizing the differential pressure limits or terminates the loss of coolant from the RCS and permits the restoration of RCS inventory. Continued mitigation is accomplished by keeping the differential pressure as low as possible during the subsequent cooldown and depressurization of the RCS, thereby limiting radiological releases and ensuring that the affected SG does not overfill. The extra borating system is initiated to prevent recriticality. Eventually, conditions for operating the residual heat removal system (RHRS) are met.

Two different limiting cases are analyzed: one in which the potential for radiological releases is maximized, and another in which the potential for overfilling the affected SG is maximized.

7.5.1 Limiting Radiological Release Scenario

In the limiting case for radiological release, the charging pumps are initially operating, a LOOP occurs when the reactor trips, and a single failure occurs in the MSRT of the affected SG: the MSRCV is postulated to stick fully open. This failure forces the release of activity from the affected SG to the atmosphere and maximizes the dose consequence of the event until the MSRIV closes automatically on low SG pressure. In addition, the EFW pump for the affected SG is assumed to be unavailable due to maintenance; this condition maximizes flashing of the break flow, which contributes to the severity of the radioactive release to the atmosphere.

Table 7-2 presents the sequence of events for the limiting radiological release scenario. The postulated tube rupture is assumed to occur with the plant operating at hot full power with both CVCS pumps operating and with letdown isolated. The pressurizer level and pressure do not decrease sufficiently to cause an RT. The operator detects the event through high activity alarms in the affected SG steam line and blowdown line. The operator begins to take action at 30 minutes and completes the initial SGTR mitigation steps within an additional 10 minutes.

Figure 7-10 shows that reactor power decreases initially because of the reactivity feedback due to RCS depressurization. The operator trips the reactor at 1800 sec; the trip is assumed to cause an LOOP with subsequent de-energizing of the RCPs, charging pumps, and MFW pumps. Figure 7-11 shows the pressures in the primary

system and in the affected SG. Primary pressure starts to decrease initially, and then increases because of the injection from two CVCS pumps. It decreases rapidly after the RT.

Because a LOOP is assumed concurrent with the RT, SG pressure increases. The operator is assumed to complete SGTR mitigation actions at 2400 sec. These actions include closing the main steam isolation valve (MSIV) in the affected SG, resetting its MSRT setpoint to the high value, isolating its EFWS and blowdown lines, starting the EFW pumps, and initiating a partial cooldown of the unaffected SGs using their MSRTs. Pressure in the affected SG reaches the MSRT setpoint at 2450 sec. When the MSRCV opens, it is assumed to fail fully open and cause a rapid decrease in the affected SG's pressure. MSRT relief from the affected SG is terminated when its MSRIV closes automatically at the low SG pressure setpoint of 570 psia, at 2570 sec. Subsequently, the affected SG's pressure equalizes with the primary pressure at about 1250 psia, and then begins to decrease slowly as the unaffected SGs remove heat from the RCS.

MHSI flow begins when the RCS pressure falls below the MHSI shutoff head. Partial cooldown is complete in the unaffected SGs at 3600 sec once the pressure in the SGs has been reduced to 870 psia. At this time, the operator continues the cooldown at 90°F/hr and starts the EBS to provide sufficient boration. EBS flow continues until the EBS tanks empty at approximately 14,000 sec. MHSI is terminated by the operator when the core exit subcooling exceeds 50°F, at 5412 sec. The primary system is refilled at this time, as shown by the pressurizer level (Figure 7-12).

Primary pressure continues to decrease slowly beyond this time due to the heat removal from the unaffected SGs. During this interval, the operator opens the pressurizer safety relief valves (PSRVs) occasionally to accelerate the decrease in primary pressure (Figure 7-11). This action equalizes the primary and secondary pressures in the affected SG, thereby minimizing break flow (Figure 7-13).

Inventory in the affected SG stabilizes before reaching an overfilled condition, as shown by the SG wide-range level (Figure 7-14). This stabilization constitutes a controlled state. The analysis is stopped at 10,000 sec. The operator continues with the cooldown and depressurization process to reach the RHRS entry conditions; the RHRS cools the RCS to cold shutdown conditions.

7.5.2 Limiting Overfill Scenario

In the limiting case for overfill, the charging pumps are initially operating, a LOOP occurs when the reactor trips, and the LOOP coincident with the SIS starts the EFW pumps. The assumed single failure is that the EFW flow control valve for the affected SG fails in the open position, causing the SG level to increase past the EFW shutoff setpoint. This failure maximizes the overfilling of the ruptured SG. In addition, an EFW pump feeding one of the intact SGs is assumed to be unavailable due to maintenance.

The sequence of events for the SG overfill case is shown in Table 7-3. The early part of the transient is similar to that of the radiological case. The postulated tube rupture is assumed to occur with the plant operating at hot full power, with both

charging pumps operating, and with letdown isolated. The reactor is manually tripped by the operator at 1800 sec (30 min), and a LOOP is assumed to occur simultaneously with the RT. The LOOP causes the charging pumps, RCPs, and MFW pumps to trip.

The ruptured SG is isolated within 10 min of the RT (i.e., its MSIV is closed and its MSRT setpoint is raised to 1405.5 psia) prior to the manual initiation of an SIS and the start of the partial cooldown at 2400 sec (40 min). The pressure response of the RCS and the affected SG, illustrated in Figure 7-15, shows that following the RT, the primary system pressure initially increases (as a result of the turbine trip) and then drops rapidly, and that the SG pressure increases in response to the turbine trip with the turbine bypass system unavailable due to the LOOP.

It is assumed that the operator identifies the EFW control valve failure once the SG 4 (ruptured SG) level exceeds the 82% wide-range SG level setpoint (approximately 10 min after the failure) and closes the EFW isolation valves to SG 4. Figure 7-16 shows EFW flow rates, and Figure 7-17 shows wide-range SG levels.

MHSI flow starts at about 3500 sec when the primary system pressure drops below the MHSI pump shutoff head. The partial cooldown is complete at 3600 sec, when the secondary system pressure has been reduced to 870 psia. At this time a 90°F/hr cooldown is initiated with the SGs of the three intact loops via their MSRTs.

At about 3660 sec, the operator manually initiates the EBS pumps to add concentrated borated water to the primary system and to provide RCS makeup. The operator realigns the flow from EFW train 2 at approximately 4260 sec to feed both SG 2 and SG 1 (SG 1 has not had EFW flow before that time because of preventive maintenance on its associated EFW pump).

The operator terminates MHSI flow at 5306 sec when the core exit subcooling exceeds 50°F. The pressurizer is refilled at this time.

Subsequent to the end of the partial cooldown (3600 sec), the operator opens the PSRVs several times to help decrease the primary system pressure. The primary and secondary system pressures equalize at about 6000 sec (Figure 17-15), thereby halting the flow through the ruptured tube (Figure 17-18).

Because of the delayed isolation of the EFW flow to the affected SG, the wide-range level in that SG approaches 90% at about 14,000 sec (Figure 7-17). However, the SG does not overfill, and the liquid inventory in the affected SG ultimately stabilizes; thus, a controlled state is achieved. The analysis is terminated at 28,800 sec (8 hr). The operator would then continue with the cooldown and depressurization process to reach the RHRS entry conditions, which would take the plant to cold shutdown.

7.5.3 Analyses Results

The results of the limiting radiological release and limiting overfill analyses show that with penalizing assumptions, the SGTR event is controlled by a combination of automatic and operator actions. Specifically:

- The radiological releases are below 10 CFR 100 regulatory limits (or within the limits of 10 CFR 50.67 for Alternate Source Term).
- The liquid inventory in the affected SG does not increase to a point where overflow of the SG is a concern.
- These analyses extend to the time when the leak is terminated by pressure equalization between the RCS and the affected SG. Termination of the leak terminates the potential for additional radiological release.

Table 7-1 SBLOCA - Sequence of Events for 6.5-in. Break with LOOP

Event	Time(s)
Begin analysis	0
Break opened	0
RT	4.493
RCPs tripped	4.494
SIS signal	16.807
EFW initiated (Loop 1 and 4)	76.807
MSRIV opens	114
MSRCV closes (faster SG depressurization)	134
MSRCV reopens to control SG depressurization at a rate of 180°F/hr	170
Loop seal clearing - Loop 2	234
Loop seal clearing - Loop 3	237
Broken loop 4 MHSI delivery began	246
Intact loop 1 MHSI delivery began	246
Break uncover	250
Accumulator injection (Loop 1, 2, and 3 and 4 respectively)	346
Loop seal clearing - Loop 1	360
PCT occurred (1638, node #31)	360.3
Loop seal clearing - Loop 4	362
Broken loop 4 LHSI delivery began	380
Intact loop 1 LHSI delivery began	380
Transient calculation terminated	1000

Table 7-2 SGTR Radiological Case - Sequence of Events

Event	Time (s)
DEG rupture of a single U-tube on the hot side of the tubesheet	0
CVCS charging pumps start	204
Manual RT with LOOP MFW pumps and RCPs lose power CVCS charging pumps lose power	1800
Initiate closure of affected SG MSIV Reset affected SG MSRT setpoint to 1405.5 psia, affected MSRT closes SG blowdown isolates CVCS isolates Start of Partial Cooldown in unaffected SGs Isolation of EFW in affected SG Start EFW pumps, EFW pump in affected SG assumed unavailable (maintenance) Start MHSI pumps	2400
Affected SG pressure increases to MSRT setpoint, MSRCV fails open in fully open position (single failure)	2450
Affected SG MSRIV closure initiated on low SG pressure	2570
Partial cooldown ends in unaffected SGs Initiate 90°F/h cooldown in unaffected SG using MSRTs Manual Initiation of EBS pumps to add concentrated boron and provide RCS makeup	3600
Terminate MHSI flow, subcooling > 50°F	5412
Operator cycles PSRV to maintain RCS pressure approximately equal to affected SG pressure	> 3600
End of calculation EBS running, EBS tanks estimated to empty at 14,131 seconds	10,000

Table 7-3 SGTR Overfill Case - Sequence of Events

Time (seconds)	Event
0	DEG rupture of a single U-tube on the hot side of the tubesheet
204	Start 2 CVCS charging pumps
1800	Manual Reactor Trip with LOOP
1801	MFW pumps and RCPs lose power CVCS charging pumps lose power
2400	Manual SI start
2400	Start of Partial Cooldown
2401	Initiation of EFW (SI + LOOP), EFW pump 1 PM SG blowdown isolates, EFW 4 CV fails fully open
2401	Initiate closure of affected SG MSIV Reset affected SG MSRT setpoint to 1405.5 psia, affected MSRT closes
3061	EFW flow to SG 4 isolated
3600	End of Partial Cooldown, Initiate 90°F/hr SG cooldown in 3 intact SGs using MSRTs
3660	Manual Initiation of EBS pumps to add concentrated boron and provide RCS makeup
4261	EFW 2 re-aligned to feed SG 1 & SG 2
5306	Terminate MHSI flow, subcooling > 50°F
14191	EBS tanks empty, EBS pumps stop
3600 - 28800	Operator cycles PSRV to maintain RCS pressure approximately equal to affected SG pressure
28800	End of Analysis

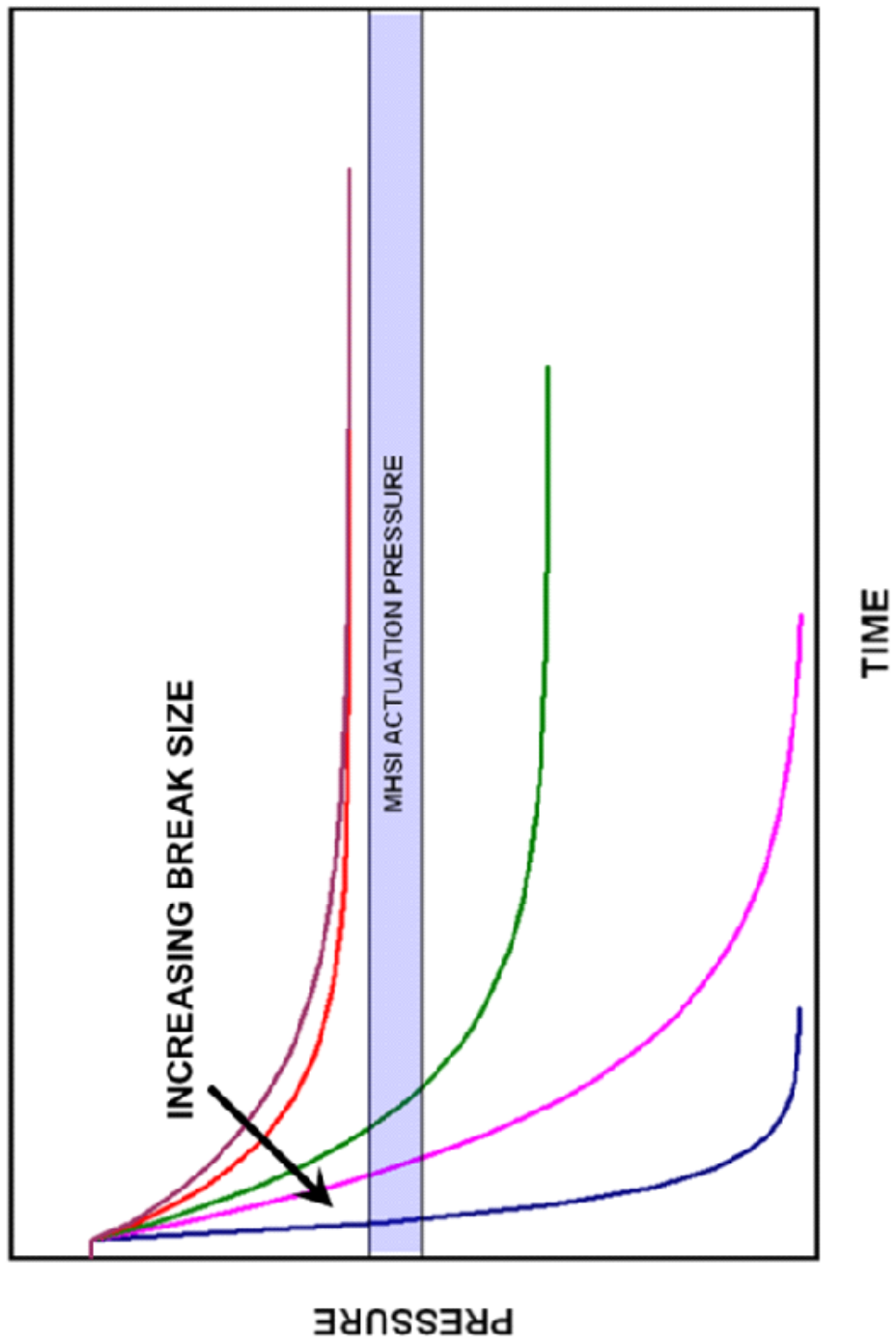


Figure 7-1 RCS Pressure for Postulated LOCAs

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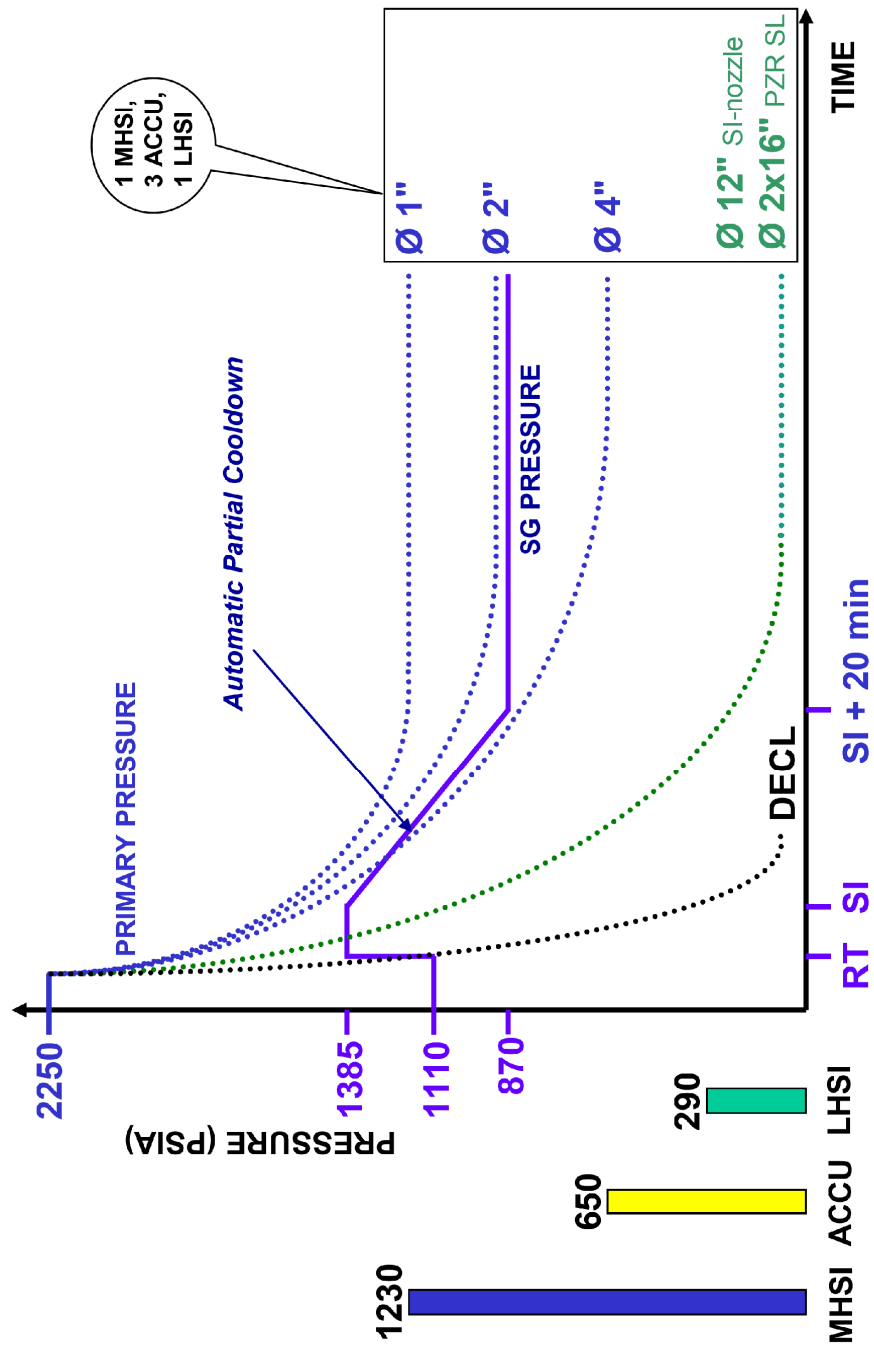


Figure 7-2 Effect of Partial Cooldown on LOCA Response

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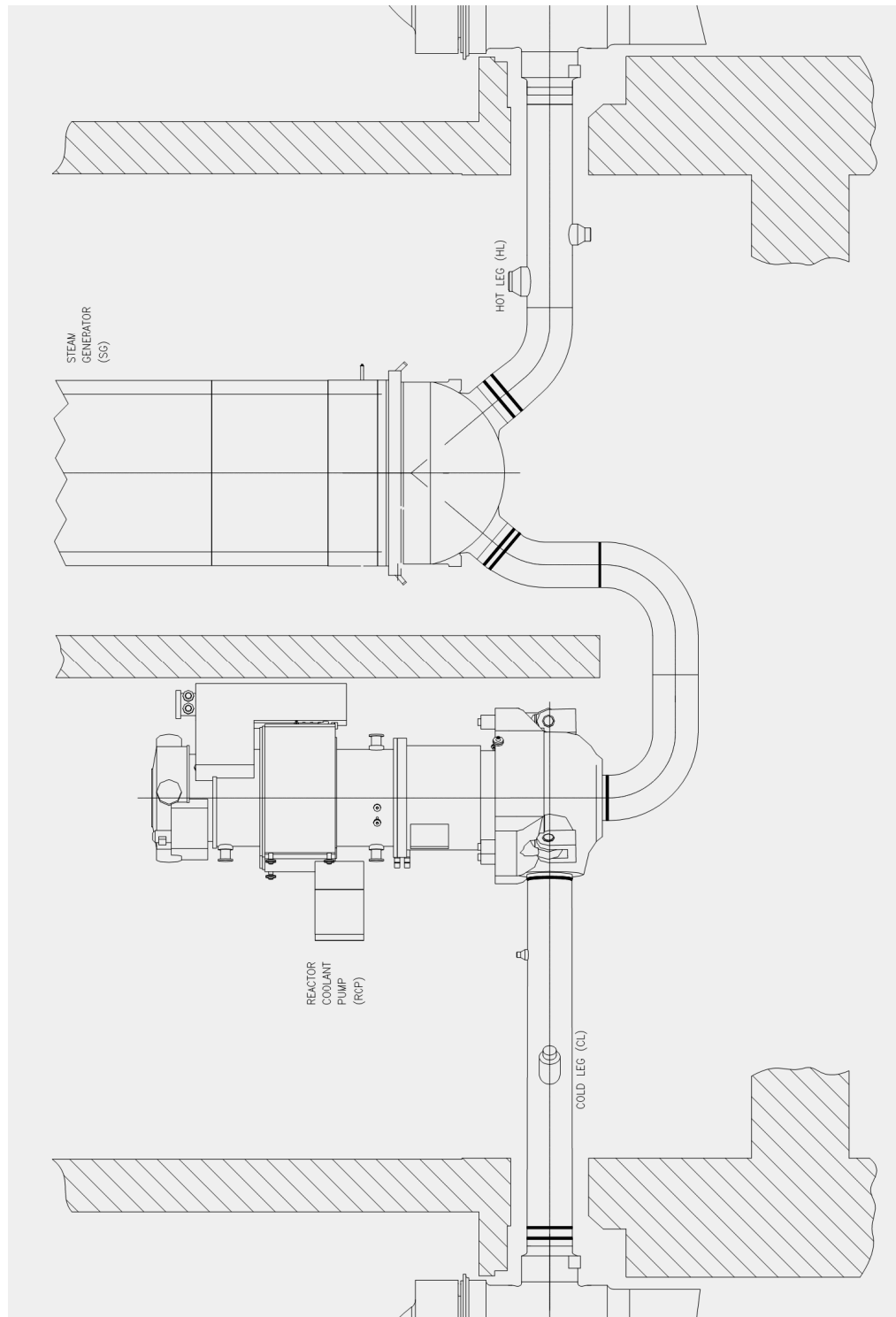


Figure 7-4 RCS Loop Seal

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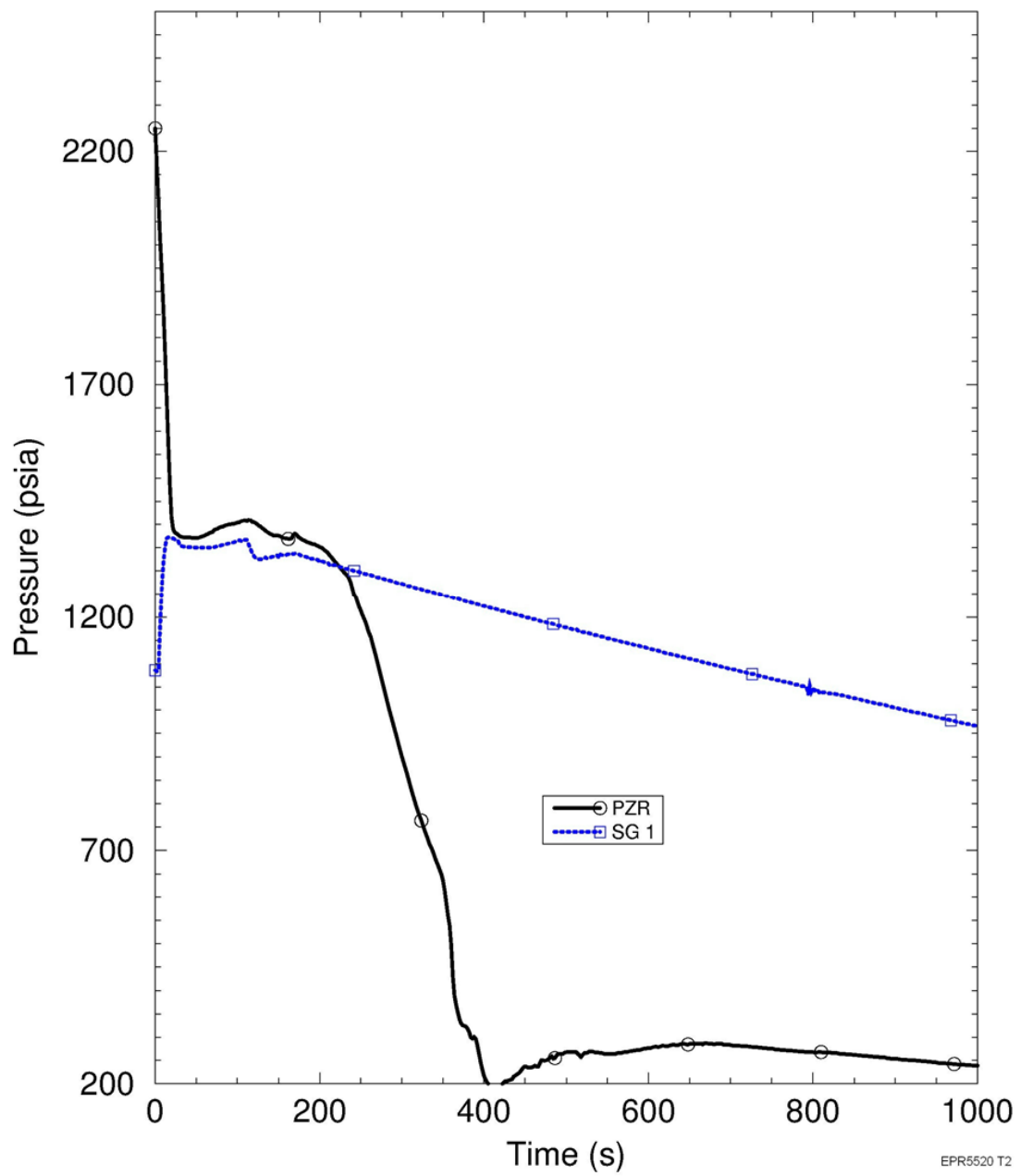


Figure 7-5 SBLOCA 6.5 Inch Primary and Secondary System Pressures

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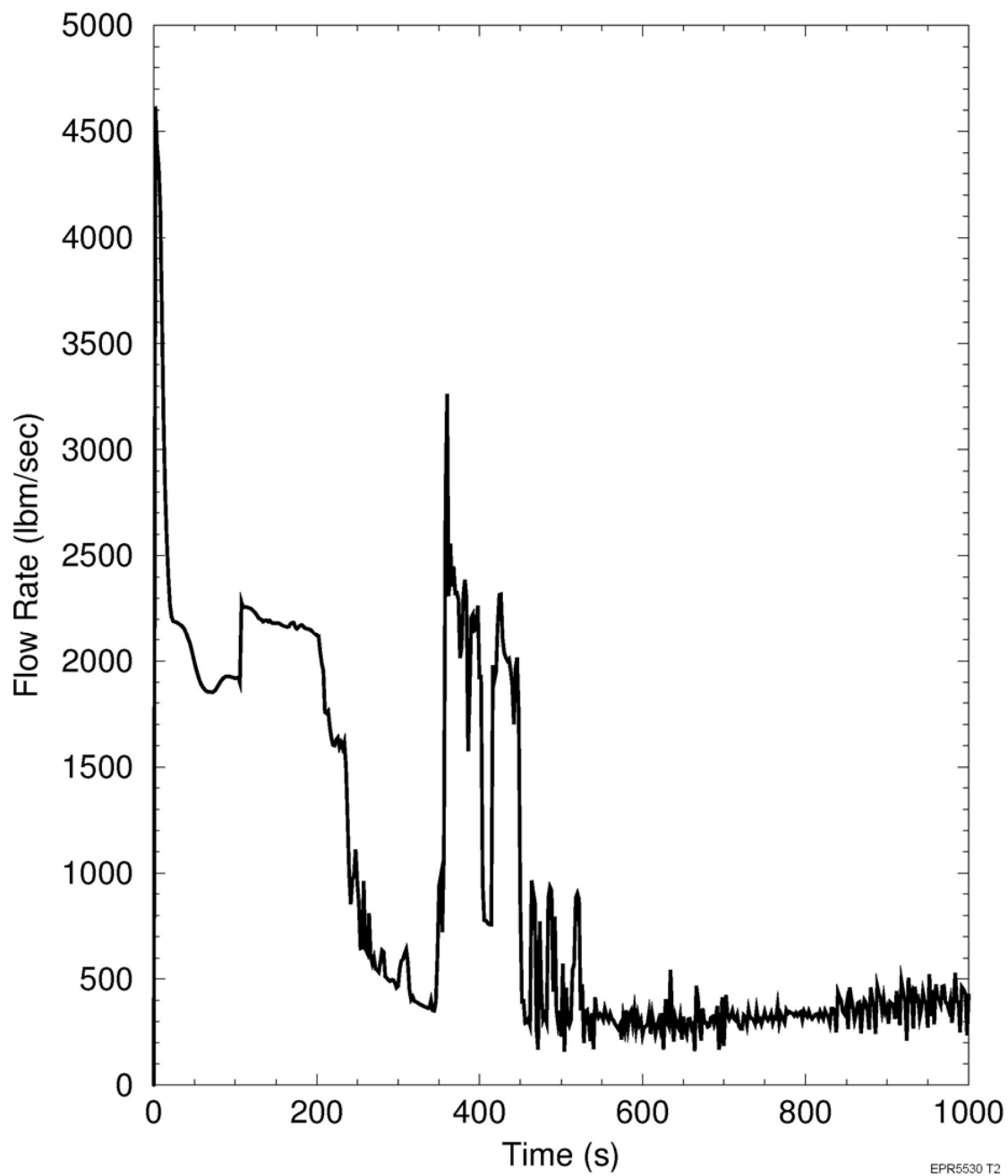


Figure 7-6 SBLOCA Break Flow Rate

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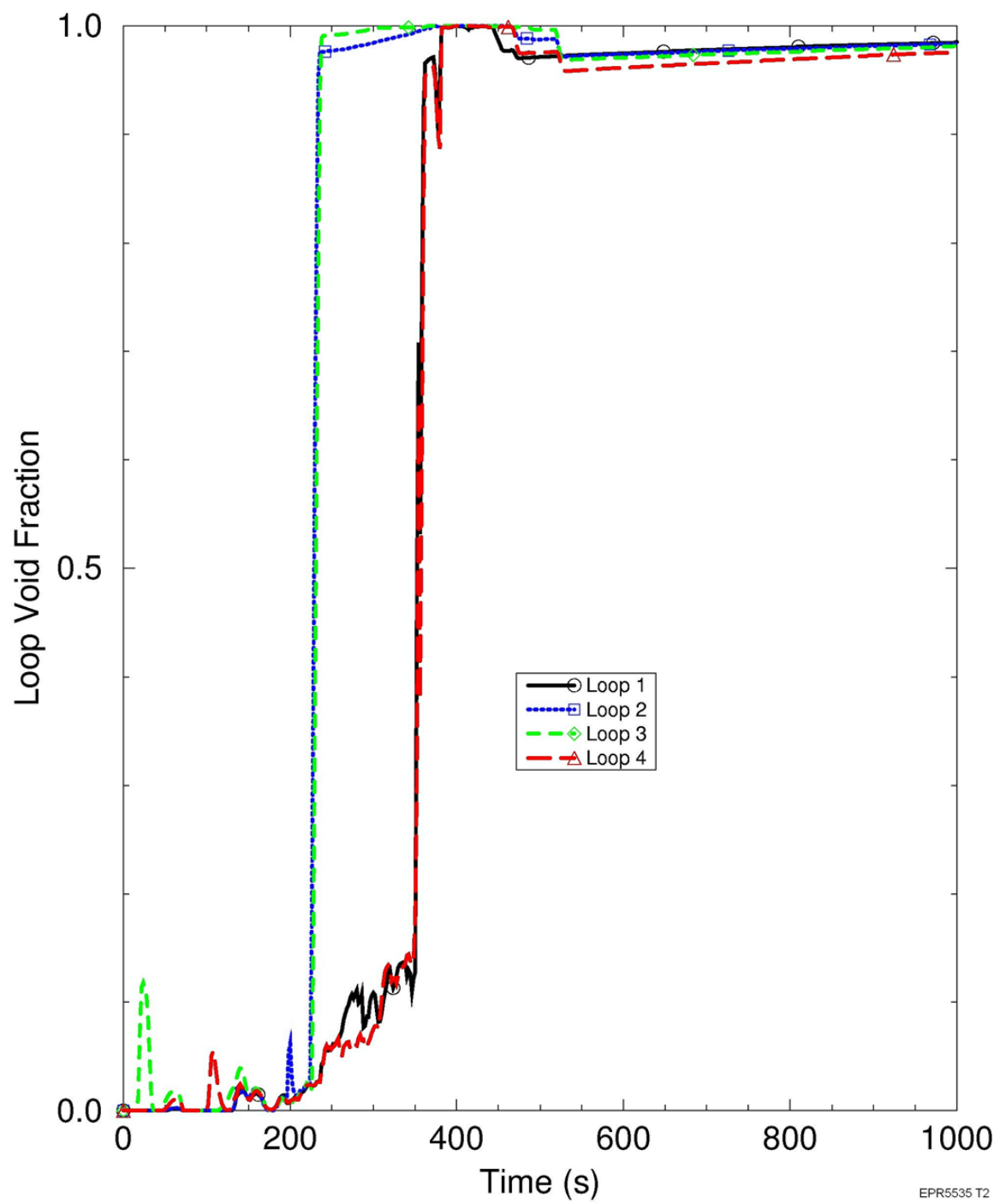


Figure 7-7 SBLOCA Loop Seal Void Fractions

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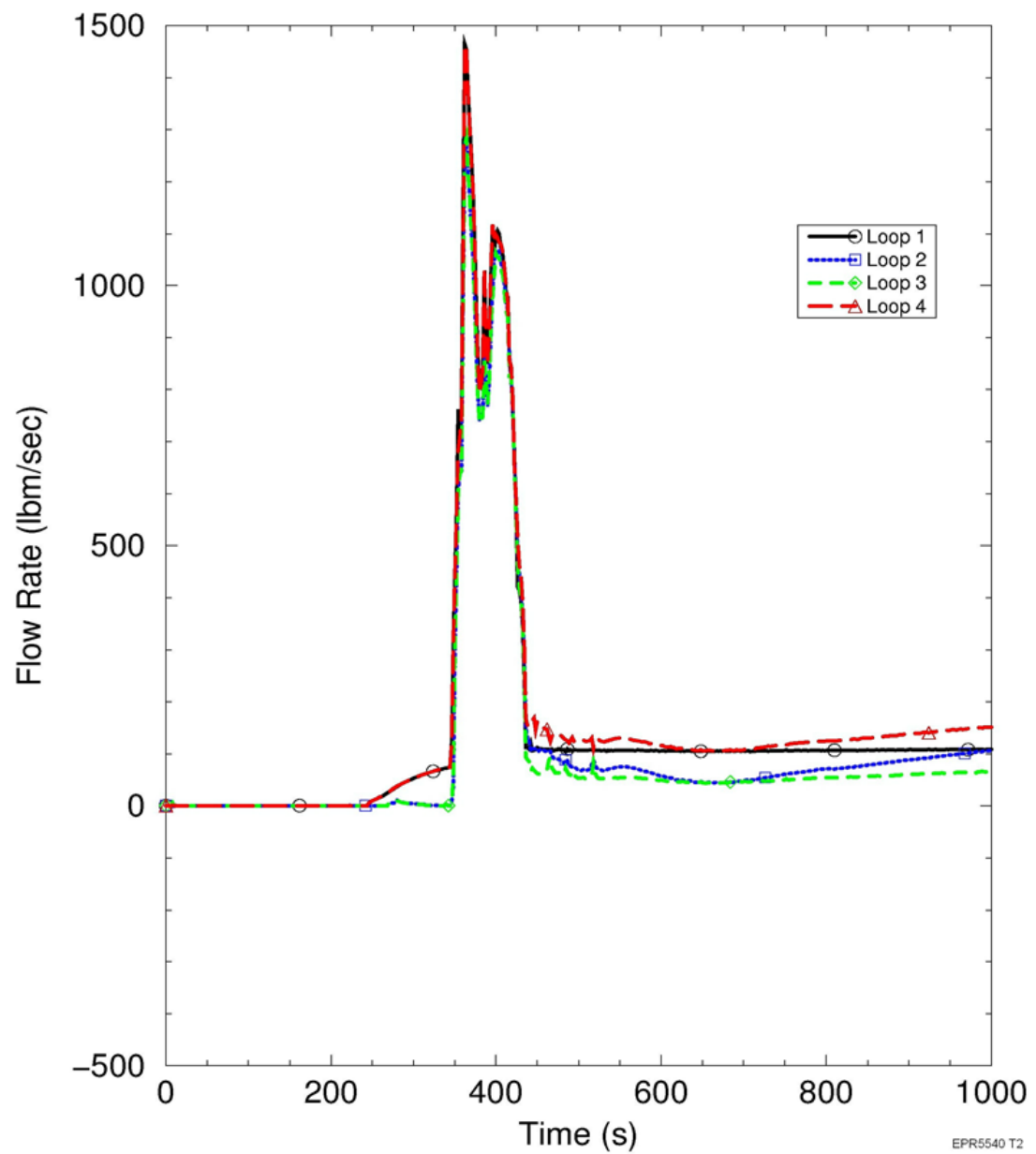


Figure 7-8 SBLOCA ECCS Flow Rates

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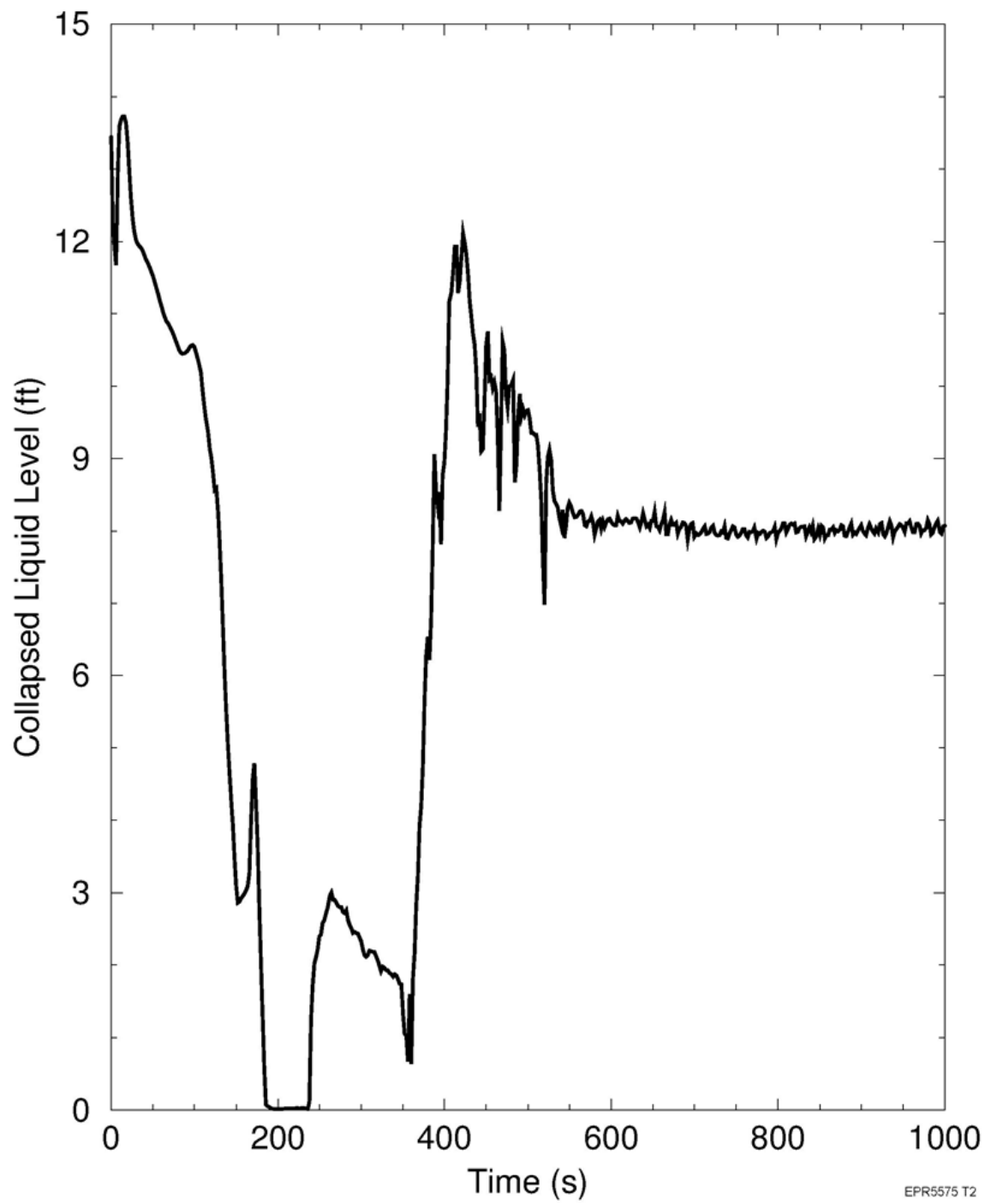


Figure 7-9 SBLOCA Hot Assembly Collapsed Liquid Level

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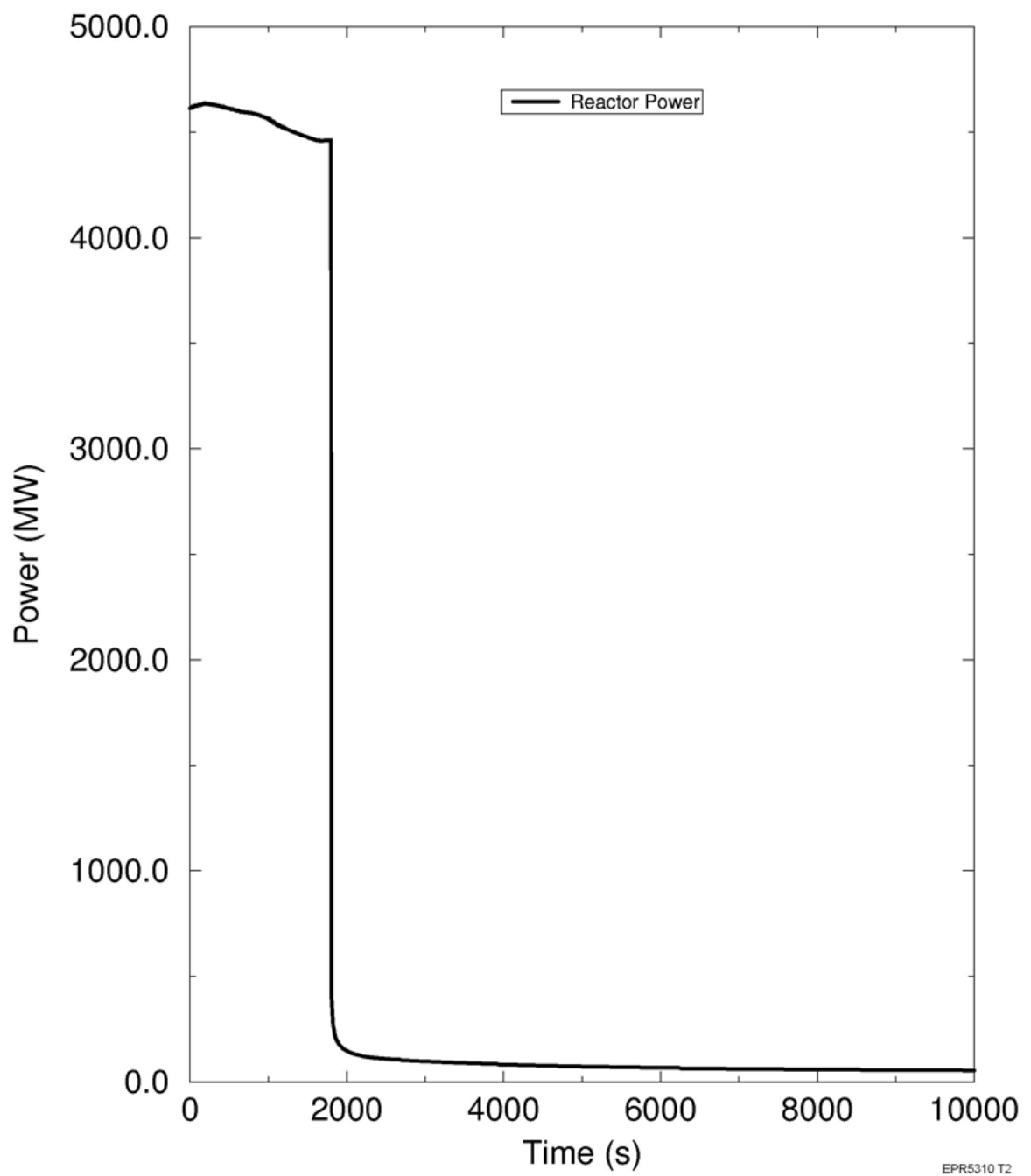


Figure 7-10 Reactor Power during SGTR (Radiological Case)

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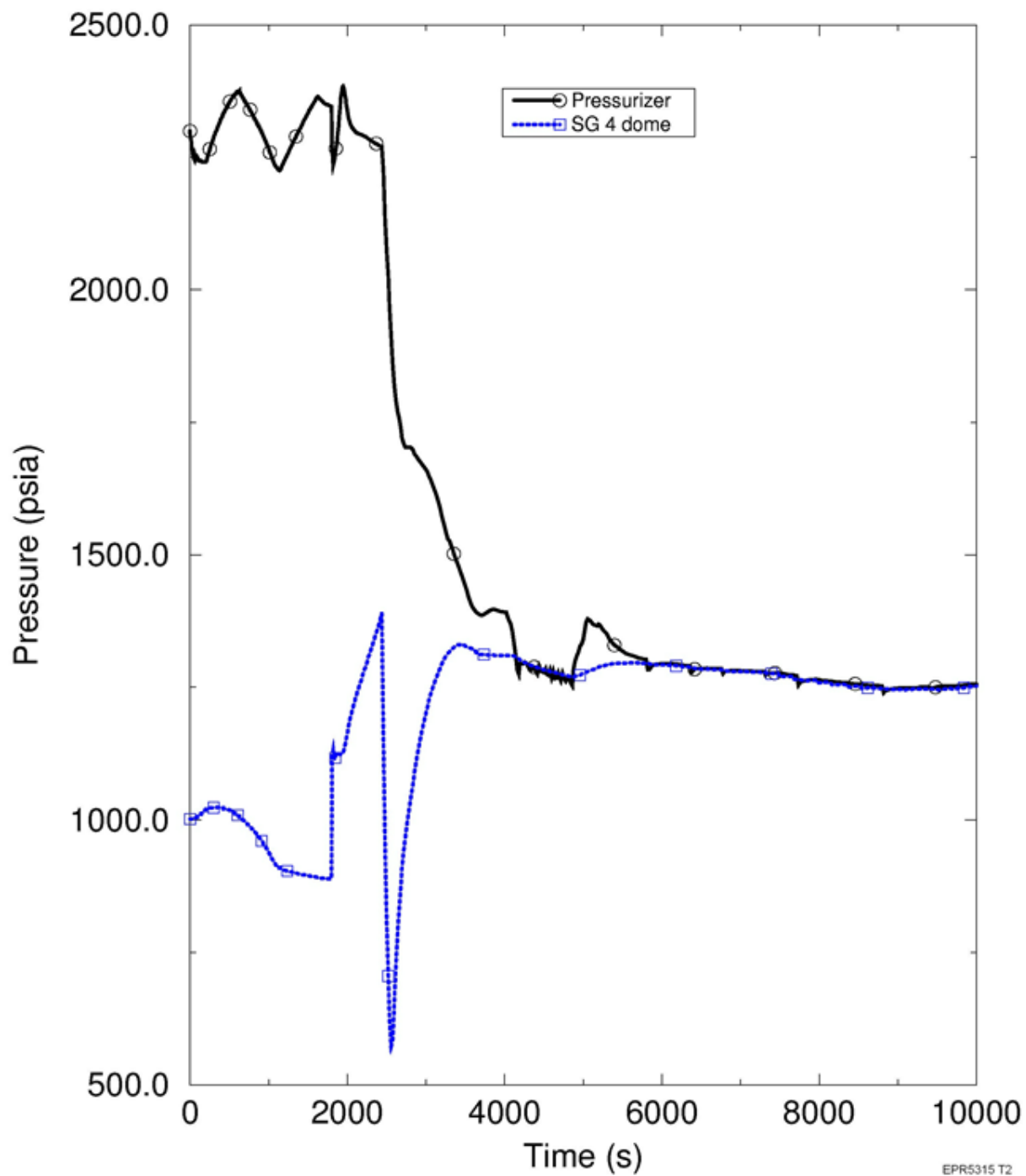


Figure 7-11 SGTR (Radiological Case) Pressurizer and Affected SG Pressures

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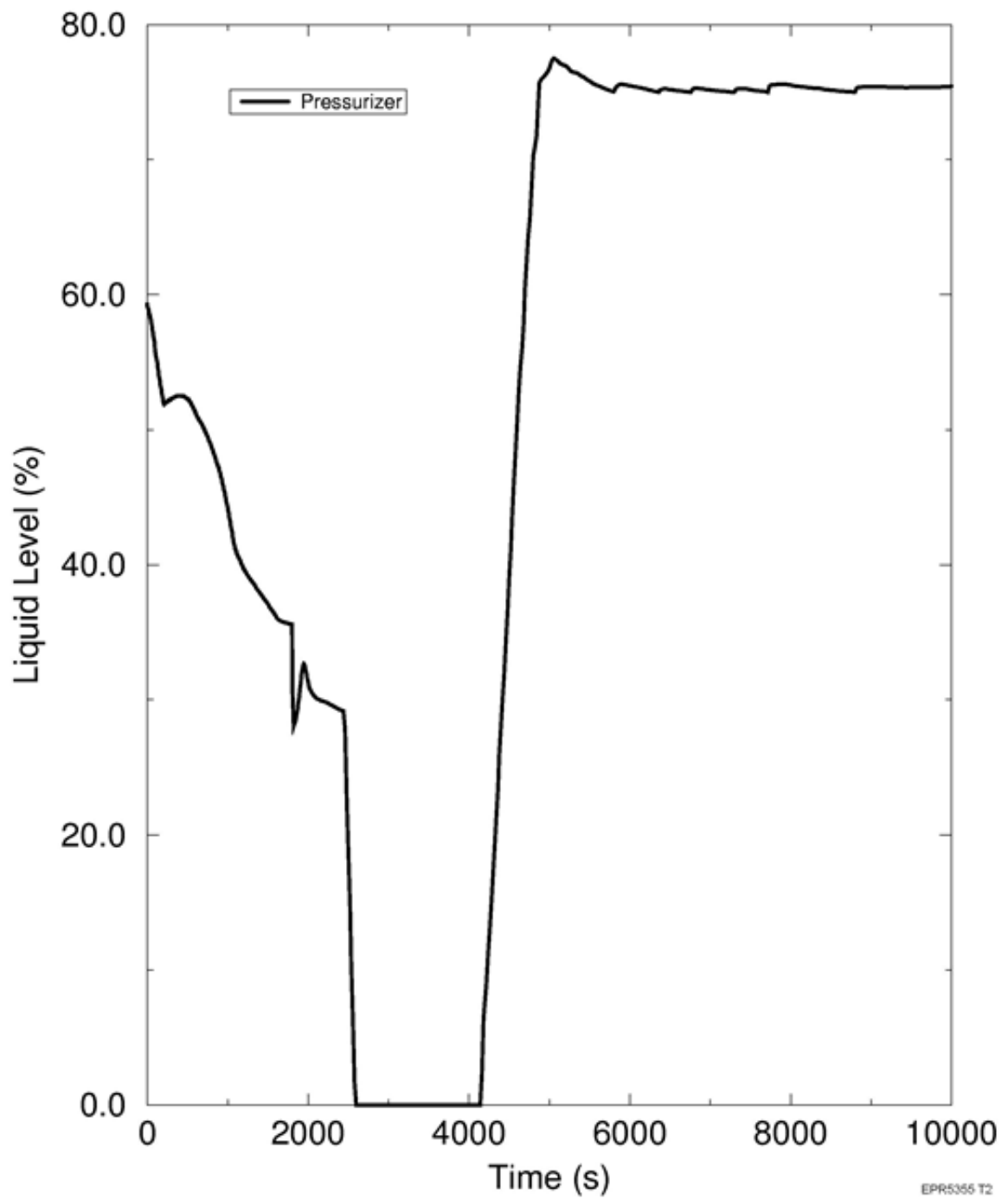


Figure 7-12 SGTR (Radiological Case) Pressurizer Level

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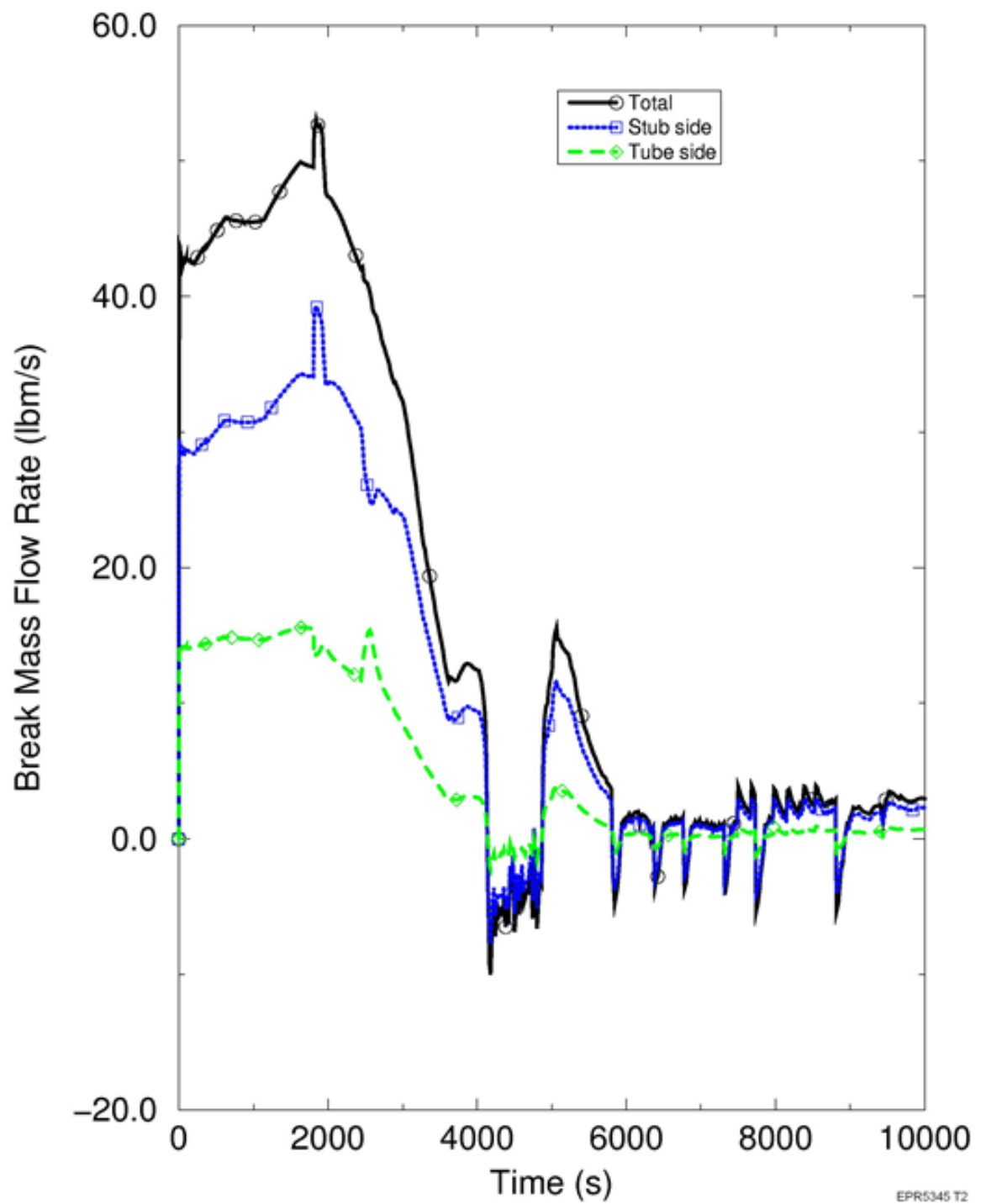


Figure 7-13 SGTR (Radiological Case) Break Flow Rate

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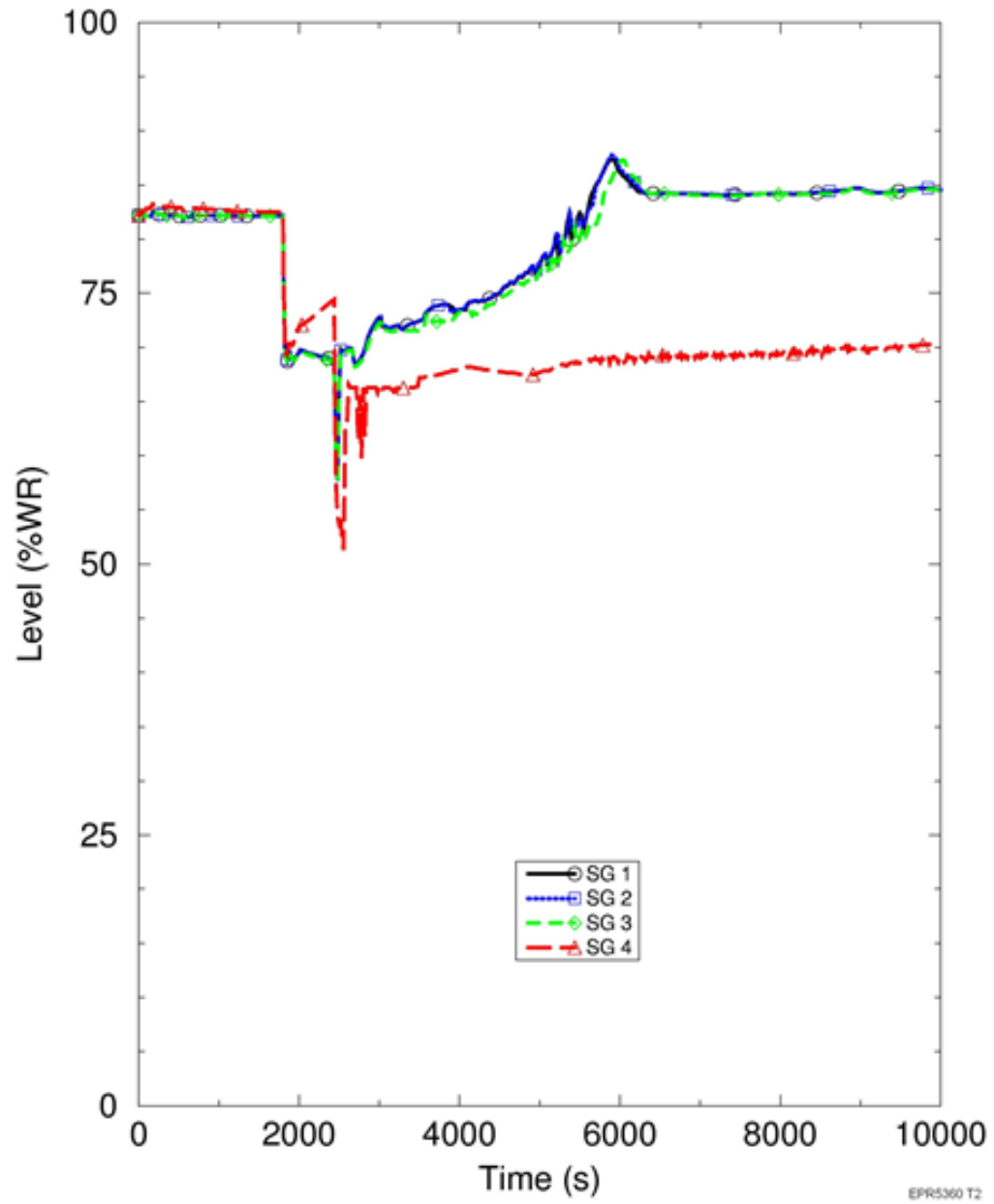


Figure 7-14 SGTR (Radiological Case) Wide-Range SG Levels

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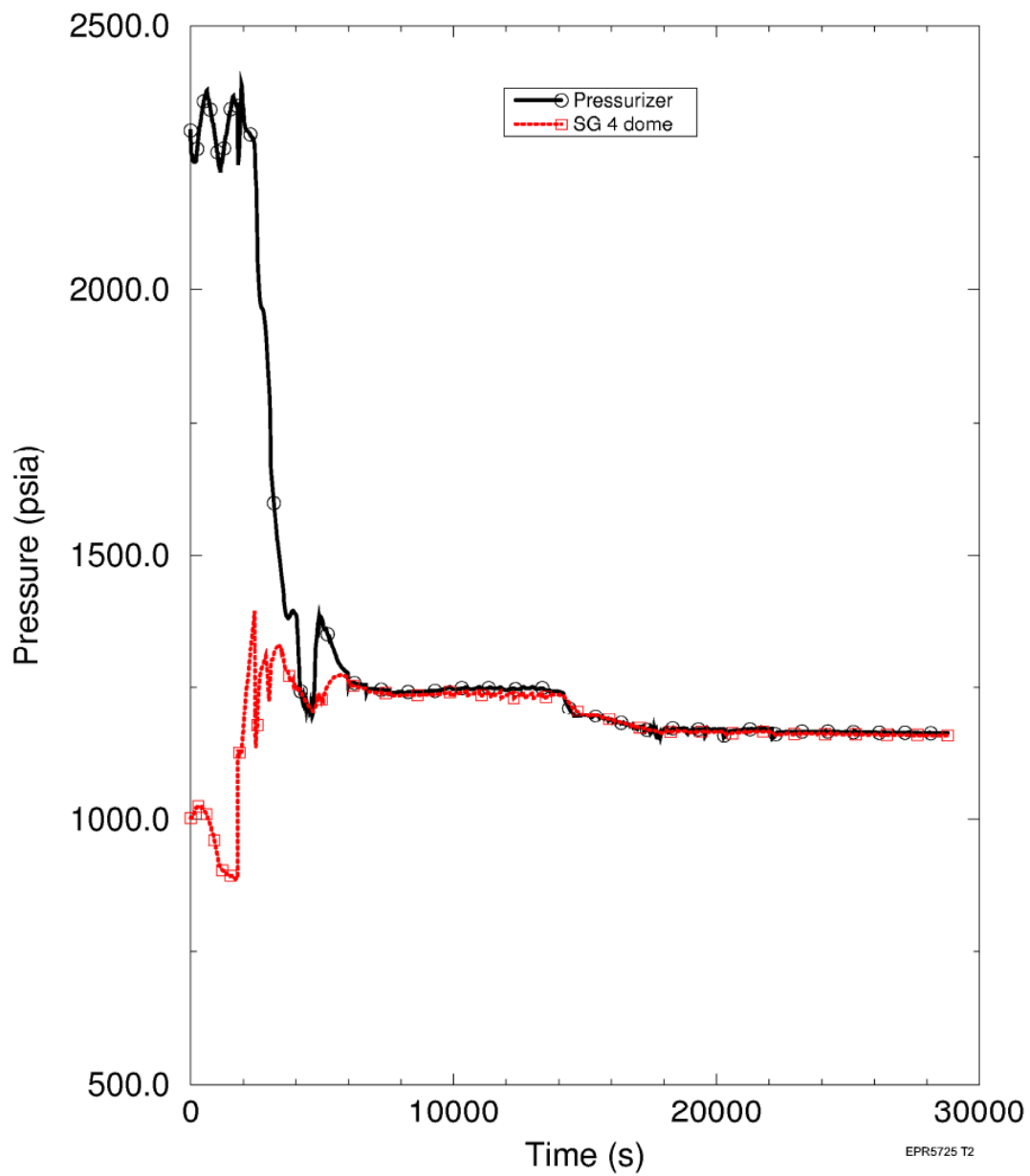


Figure 7-15 SGTR (Overfill Case) Pressurizer and Affected SG Pressures

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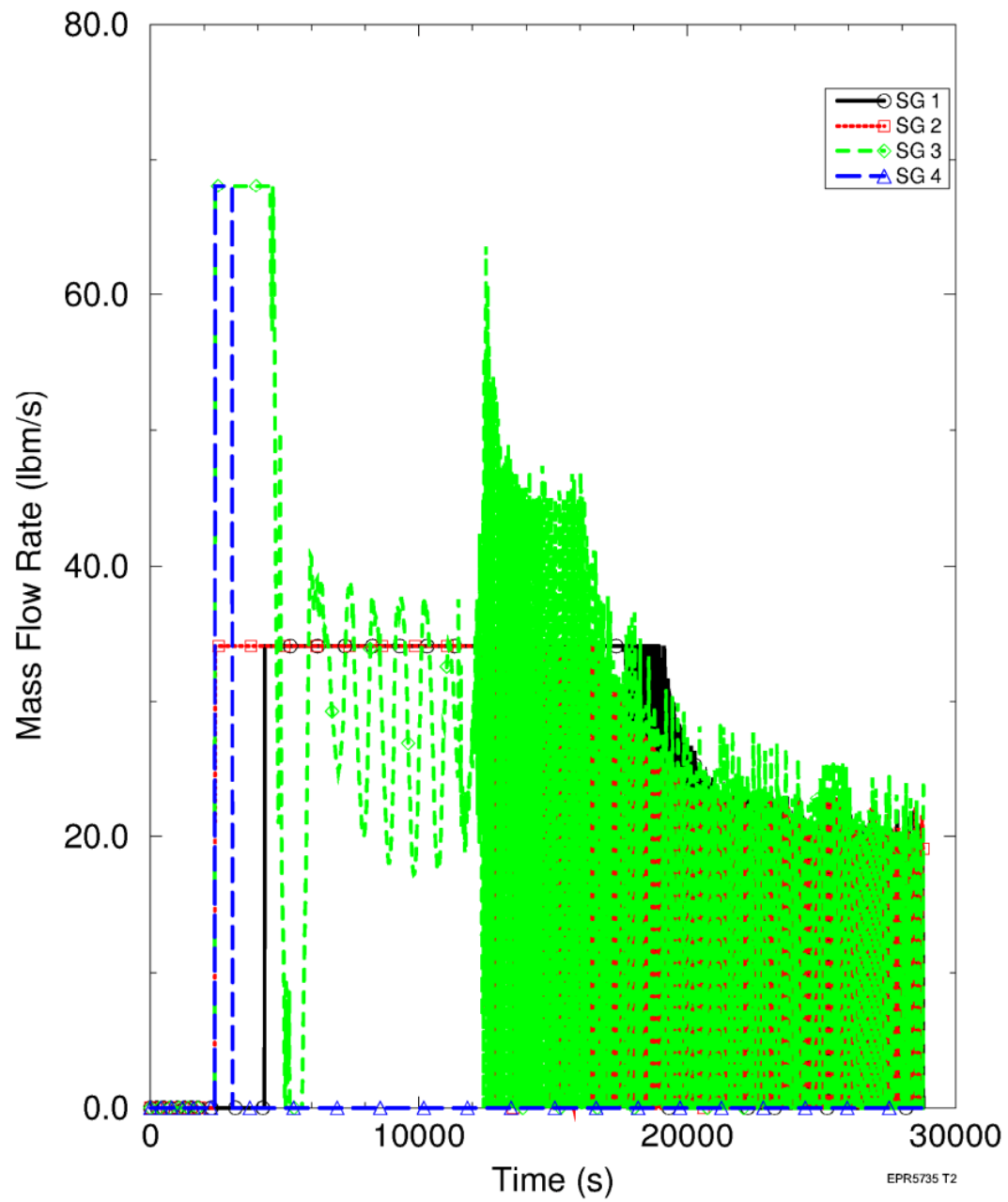


Figure 7-16 SGTR (Overfill Case) EFW Flow Rates

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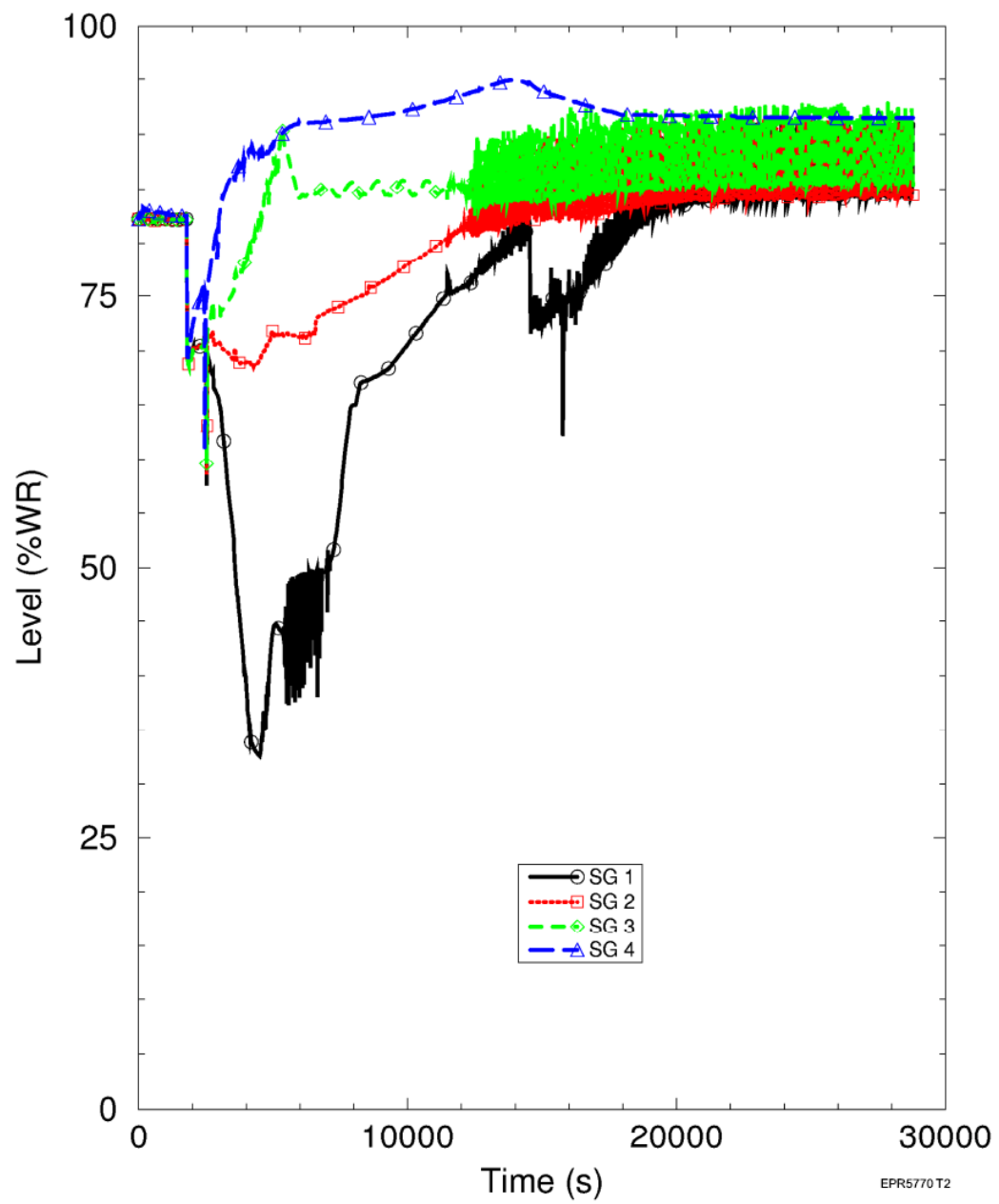


Figure 7-17 SGTR (Overfill Case) Wide-Range SG Levels

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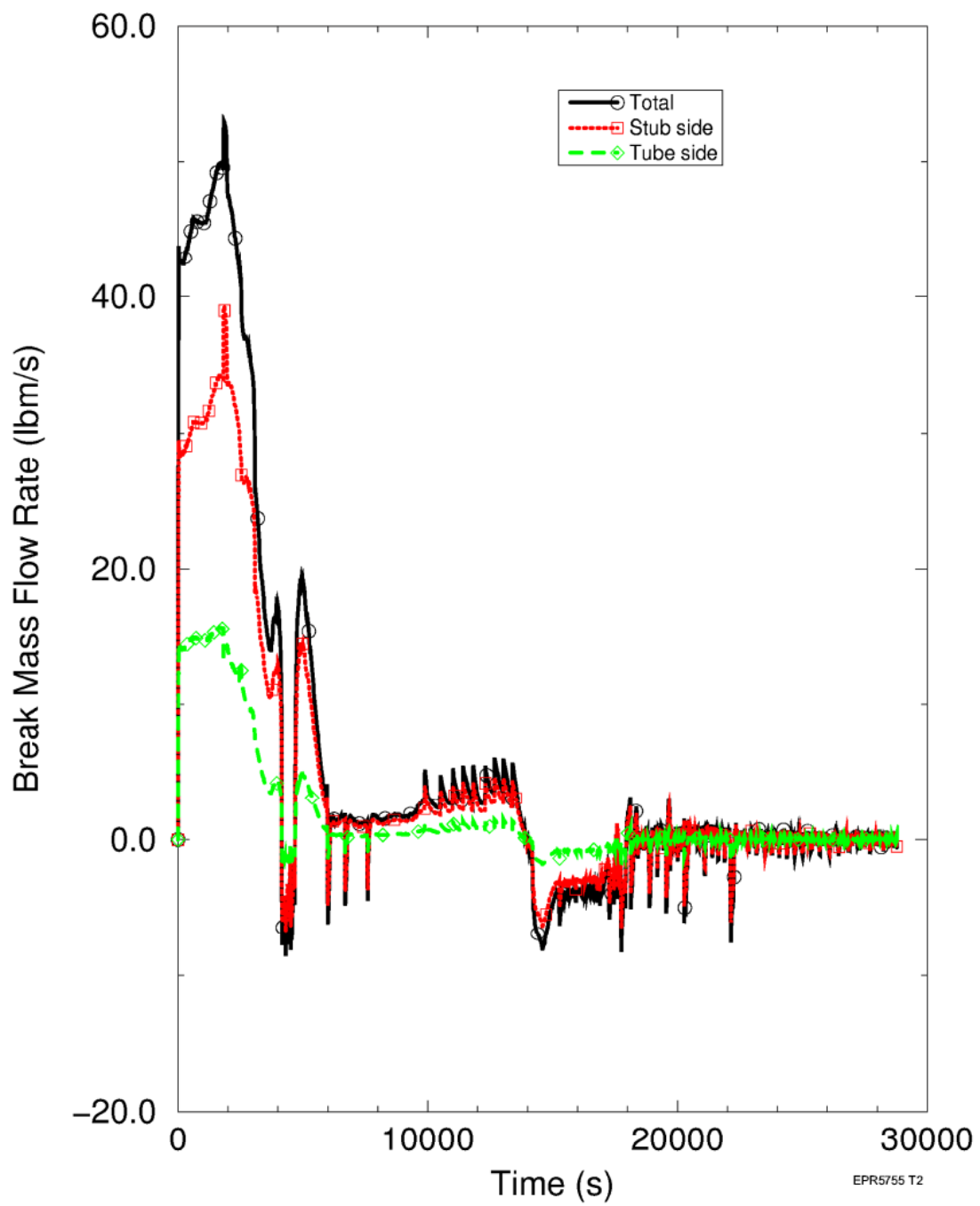


Figure 7-18 SGTR (Overfill Case) Break Flow Rate

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